Development of a Near-Bed Sediment Flux Sensor

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LONG-TERM GOALS

Our research program focuses on identifying and quantifying sediment erosion, transport, and deposition processes on the continental shelf through state-of-the-art observational techniques in both fine grained and sandy environments. In sandy environments our goal is to understand the detailed interactions and feedbacks between hydrodynamics, bedforms, and the resulting sand transport. In fine-grained environments we have been investigating the role fluid mud flows as a depositional mechanism in areas with high deposition rates.

OBJECTIVES

In certain environments bedload or near-bottom suspended load can be the dominant mode of sand transport. In particular, these modes of sediment transport can have important impacts in terms of understanding erosion and deposition mechanisms in coarser sand environments with active bedform processes. These bedform processes, which may be forced by bedload transport, have been observed to change the local seafloor elevation tens of centimeters in time scales of hours to days. (Traykovski et al, 1999) However, there is a lack of suitable observational techniques to measure bedload and near bottom suspended sand transport and their relationship to the hydrodynamic forcing. Therefore, we are developing and testing acoustic Doppler instrumentation that can quantitatively measure the bedload and near bottom suspended load flux magnitude and direction on a rapid time scale and its relationship to the hydrodynamic forcing.

APPROACH

The approach for this project is based on a combination of modeling sensor geometry and response and testing actual systems in laboratory and field environments. The modeling effort is being used to guide development of sensor geometries and signal processing schemes. These were recently tested in the WHOI 17m flume. The principle upon which this measurement is based is relatively simple. A series of acoustic pulses are scattered off the seafloor and moving near-bed particles and the amplitude and phase of these pulses are recorded. This time series is then transformed to a spectral estimate via a Fourier transform. This spectral estimate consists of a series of backscattered intensities at different Doppler shift frequencies. Each different frequency corresponds to a velocity and the intensities correspond to a concentration at that velocity. The complete scattered signal consists of a strong return from the stationary bottom and weaker returns from grains of sand moving as near-bed flux at many

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14. ABSTRACT

Our research program focuses on identifying and quantifying sediment erosion, transport, and deposition processes on the continental shelf through state-of-the-art observational techniques in both fine grained and sandy environments. In sandy environments our goal is to understand the detailed interactions and feedbacks between hydrodynamics, bedforms, and the resulting sand transport. In fine-grained environments we have been investigating the role fluid mud flows as a depositional mechanism in areas with high deposition rates.

15. SUBJECT TERMS

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different velocities. To estimate a near-bed flux, the velocity for each Doppler shift frequency is multiplied by the corresponding intensity and the results are summed. This procedure multiplies the strong intensity of stationary bottom return by its zero velocity, thus effectively canceling this contribution from the estimate. This flux estimate is essentially an estimate of the intensity weighted mean of the Doppler shift spectrum times the mean intensity. In similar systems that were designed to measure velocity and intensity in the water column pulse-pair algorithms have been used to estimate the mean velocity. These methods simply use sequential pulses to estimate a phase shift which is related to particle velocity through the Doppler equation, and then average many estimates to reduce the variance of the estimate. If this estimate is multiplied by the mean intensity a flux estimate similar to the spectral approach described above can be generated. The difference between the two techniques is that spectral technique allows coherences over longer time intervals (i.e slower velocities) to be resolved.

In flume test we examined the use of several bi-static geometries (Figure 1b) and processed the data using both pulse-pair and spectral algorithms. This bistatic configuration is similar to that used by Alex Hay in his Coherent Doppler Profiler (CDP) (Zedel and Hay, 1999). This allows measurement of 3 velocity axes and backscattered amplitude to estimate suspended sediment flux over the lower 30-50 cm above the seafloor. The final product of the work we hope will be a system that can fully resolve sediment transport phenomena that occur near the seafloor that present systems are not able to observe, and an understanding of the performance bounds of this system. This will allow future research to focus on the near bed processes that force large elevation changes in short time periods.
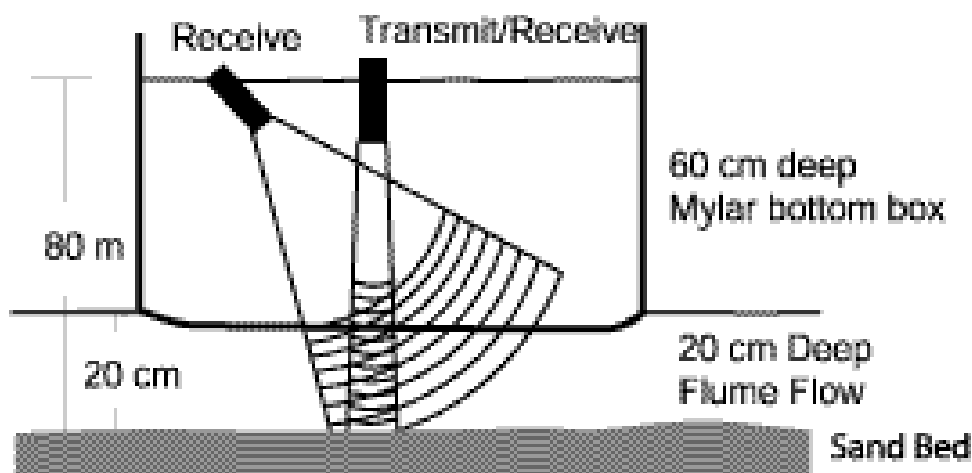

Figure 1. The bi-static geometry used in the flume test allows resolution of both bedload and suspended load fluxes. Due to the 20 cm depth of the flume an acoustically transparent bottom box was installed above the flume to house the transducers in a "field" geometry

WORK COMPLETED

The system was configured using 3 Doppler (DopBeam) transceivers from Sontek and PC based data acquisition system. The data acquisition uses a 12-bit simultaneous 16-channel analog-to-digital converter that allows 0.7 cm range bin resolution. Bench testing was performed to ensure the system synchronized all channels adequately and did not miss samples. Flume tests were performed using the sampling geometry shown in Figure 1 with several different flow velocities over a mobile sand bed. A

suction sampling system was used 10 cm downstream of acoustic sampling volume to measure in-situ bedload flux during several of the runs. The data from these runs has been examined using both spectral and pulse pair algorithms. The system was also run with a fixed flat bed and a Laser Doppler Velocimeter sampling the same volume as the acoustic system to test the velocity measurement capabilities of the acoustic system. The data from the combined laser acoustics runs has not been processed yet.

RESULTS

The mobile sand bed formed bedforms of 5 to 10 cm height and 30 to 40 cm wavelength with nominal flow speeds of 50 cm/s. While the largest scale bedforms were somewhat two dimensional many smaller scale three-dimensional features would form and rapid time-scale variability in flux was visible through the flume viewing windows. In figure 2 a run is shown where two large bedforms migrated past the sensor and then the bed evolved into a more three dimensional state. High velocity jets are visible in the upper portion of the flow downstream of bedform crests. In the lee of the bedform flow reversal is evident. The scattered intensity also showed some suspended sediment 5 to 8 cm above the bed in the lee of the bedforms. On the upstream side of the bedforms (minutes 3 through 9 and 10 through 14) high scattering intensity was confined to with 1.5 centimeters of the bed. This was consistent with both visual observations, and suction samples 3 cm above the bed were typically three orders of magnitude less than the sample at bed level. The spectral flux estimate shows high flux in the range bin with the highest intensity, or one range bin above. Flux was highest in a thin layer on the upstream side of the bedforms. Visual observations indicated that part of this flux would deposit immediately in the lee of the bedform and periodically avalanche down the lee slope and part of the upstream flux would be entrained into suspension in an eddy in the lee of the bedform. The Doppler flux estimates show the suspended sediment flux in the lee of the bedform, but do not appear to resolve the avalanching events.

In Figure 2 results from the pulse pair algorithm and the spectral approach are compared. The spectral processing results a lower estimate for velocity than the pulse pair processing away from the bed. Initial analysis indicates that this is due aliasing of high velocity components into negative velocity bins (warp-around) in the Doppler shift spectrum. Comparison with the LDV results will be used to further examine this issue. In the near-bed flux estimate the spectral approach is 20% higher than the pulse pair method. The spectrum near the bed is strongly asymmetrical with the large return from the stationary bed. The pulse-pair method appears to be biased low due to this asymmetry. The spectral approach is better able to distinguish the stationary bed since it can resolve longer coherences due the longer time window. Both methods use the same length time window (i.e for pulse pair 32 pair estimates are averaged vs. a 64 point FFT in the spectral method), however the in pulse pair the averaging is incoherent across the 64 point (32 pairs) window while with the FFT there can be coherence across the entire 64 point window.

Comparison between the suction samples and the Doppler flux estimate are difficult since the small scale three-dimensional features present on the larger more two dimensional bedforms would change geometry as they migrated the 10 cm between the acoustic sampling volume and the suction intake. However, both time series show the same general trends with high fluxes on the upstream side of the bedforms and lower fluxes in the lee. Further tests with a tall and narrow flume that only allows two dimensional bedforms would aid in providing a more useful comparison.
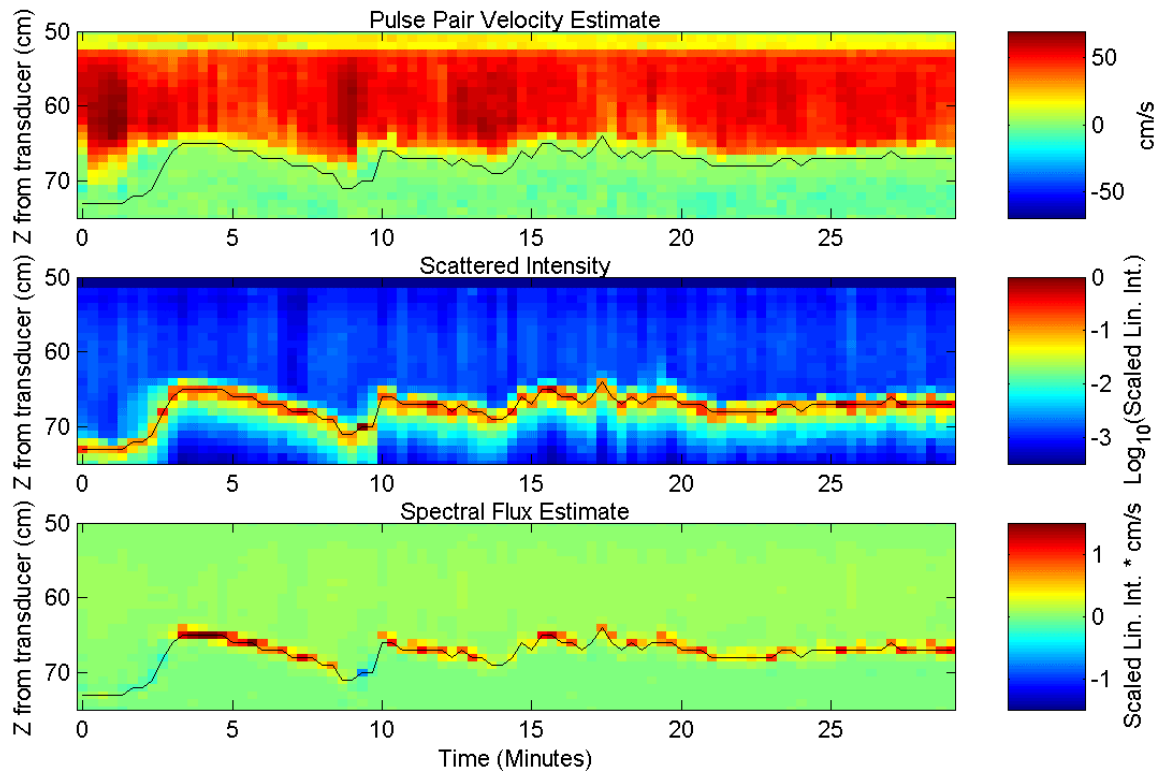
Figure 2. Upper panel: pulse pair velocity estimate with the bed as defined by the range bin with the highest scattered intensity shown as a black line. Middle Panel: Scattered intensity from transmitting on the vertical pencil beam and receiving on the fan beam transducer. Intensity units are linear, and scaled to have a maximum intensity of unity during this run. Lower Panel: Flux estimate using the spectral algorithm.

TRANSITIONS

The primary transition in this project will be from a conceptual system to a field deployable instrument. We anticipate the ability to coherently measure suspended and near bed transport processes will shed light on migration and geometry of bedforms. We will also be able to transition this type of processing to mine burial experiments in which pulse coherent single beam Dopplers will be aimed out from a NRL designed instrumented mine.

RELATED PROJECTS

This project was motivated by our work at LEO-15 where we observed wave orbital scale ripples to migrate in the onshore direction while suspended transport was in the offshore direction. The hypothesis is that bedload transport forced by asymmetric wave motions was responsible for forcing the ripple migration. The observation that there is a close relation between the spectral estimates and the pulse-pair estimates may allow us to examine bedload flux from measurements that A. Hay took in 1999-2000 at LEO-15, using DSP based hard-wired pulse pair processing.
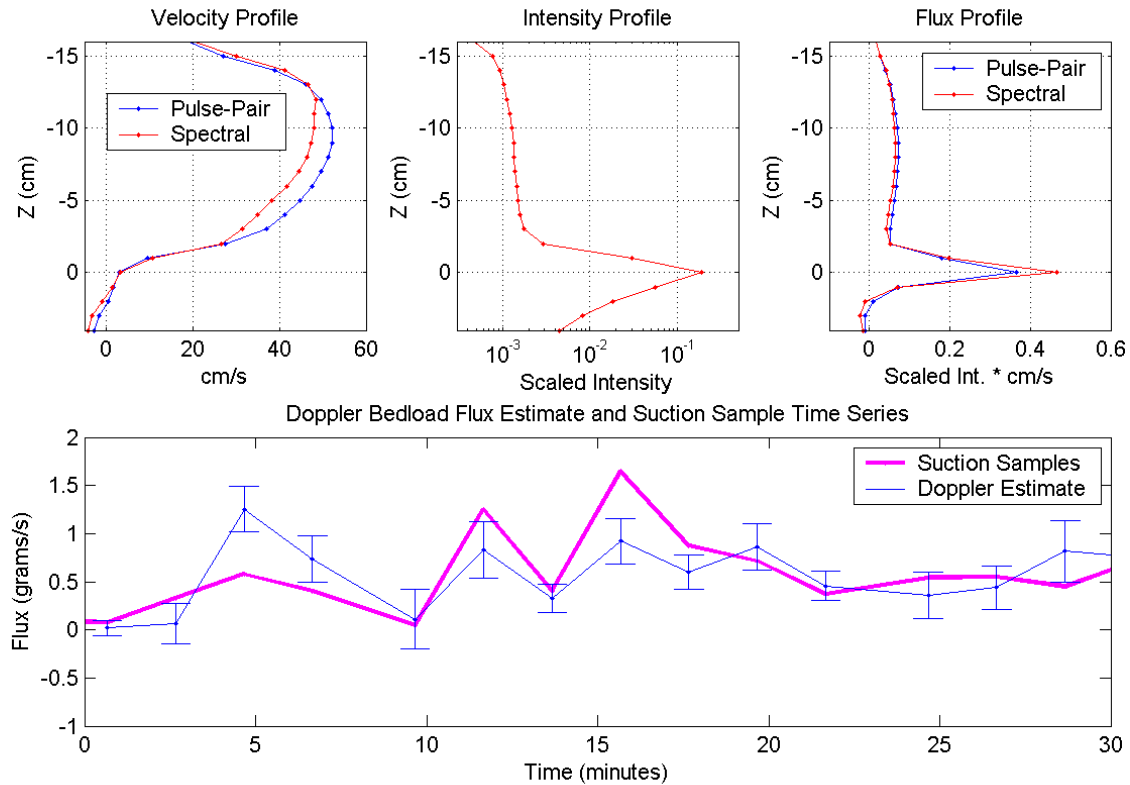
Figure 3. Upper Panels: mean profiles averaged over 30 minutes in terrain following coordinates. Lower Panel: Comparison between the Doppler estimate of nearbed flux and the suction samples. Units for the suction samples are grams per second through the intake tube. The Doppler estimate units are the scaled intensity units referred to previously multiplied by cm/s. The fact that both these units give numbers on a similar scale is coincidence.

This project is also closely related to the Y.I.P. award project "Using a Near-Bed Sediment Flux Sensor to Measure Wave Formed Bedform Migration and Formation Processes" in that the Y.I.P. project will use the technology developed in this project to measure the relative roles of bedload and suspended load flux in forcing bedform migration and geometric evolution.

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